Scale Hyperloop Final Presentation

6 May 2014

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SPONSOR: SHELL OIL CO.

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   I. Hyperloop Background
II. System Results
   i. Tubular Linear Induction Motor
   ii. Capsule
   iii. Tube
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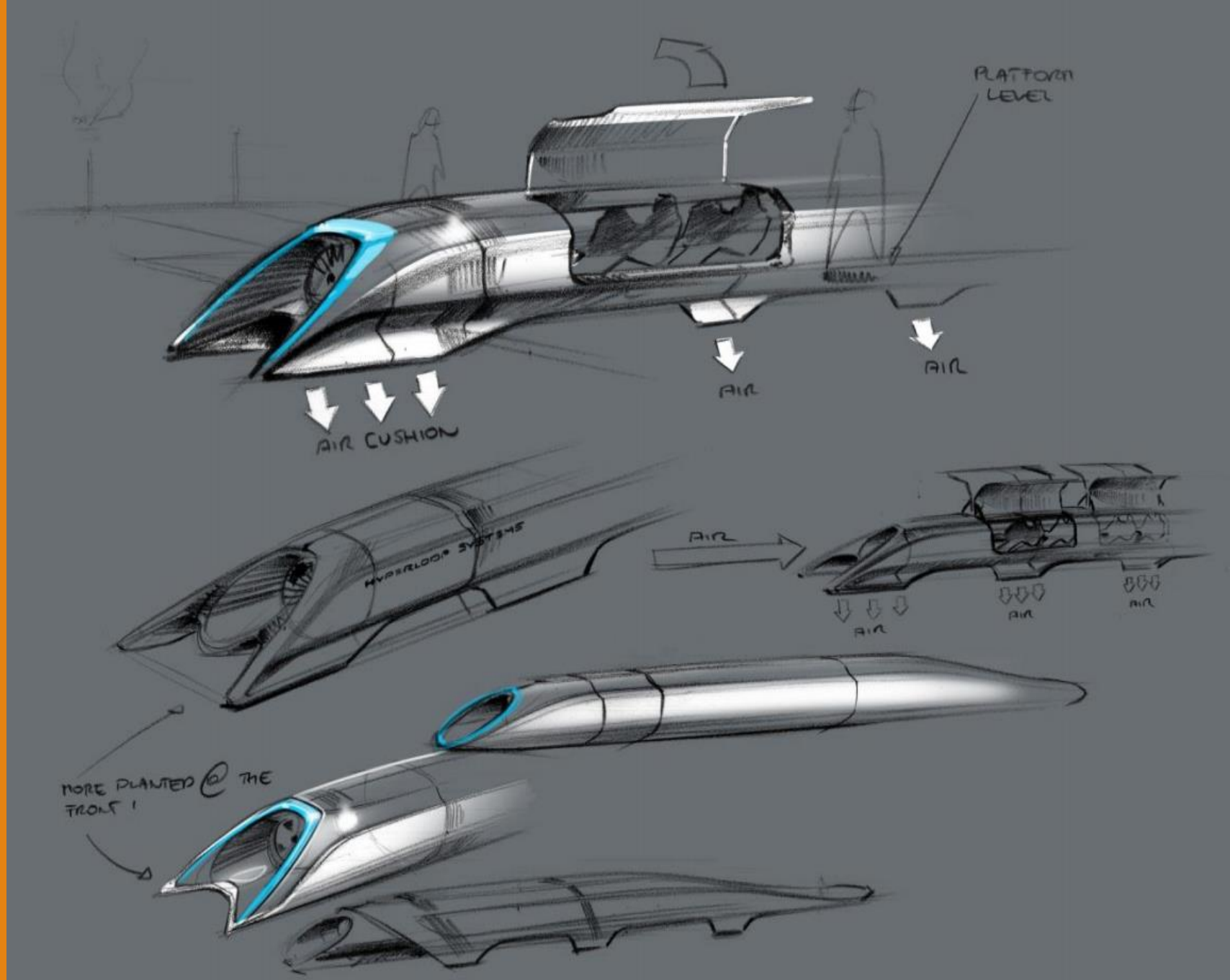
IV. Conclusions and Recommendations

What is Hyperloop?

- Brainchild of Elon Musk, transportation system in three parts:
  - Propulsion system
  - Vehicle/capsule
  - Vacuum tube
- Proposal published in a 55 page white paper
- Designed to reach near sonic speeds (~760 mph max)



DREW BELL

Project Objectives

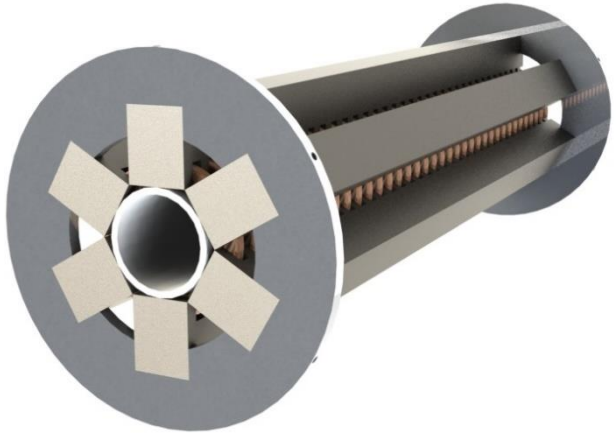
I. Produce scale prototype of system
II. Explore feasibility of concept
III. Optimize prototype performance

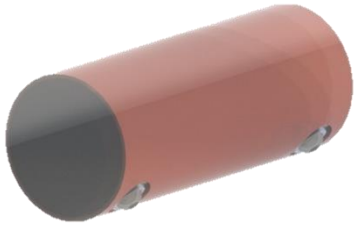
Scale Model System Architecture

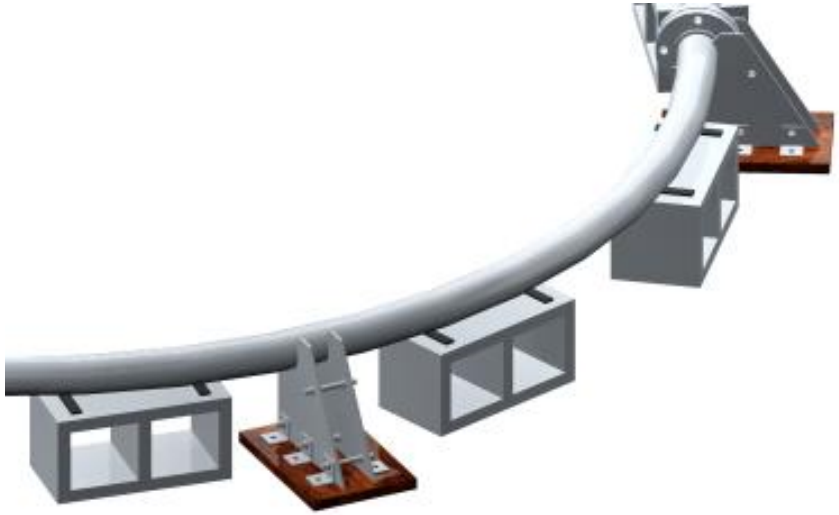
I. Propulsion System: Tubular Linear Induction Motor (TLIM)

II. Vehicle: Iron-based Capsule with Copper Jacket

III. Vacuum Tube: Evacuated 13 meter Oval Test Track





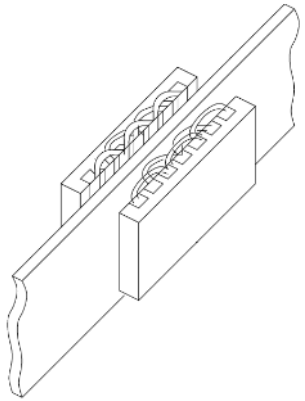


Tubular Linear Induction Motor Results

I. Propulsion System: Tubular Linear Induction Motor (TLIM)

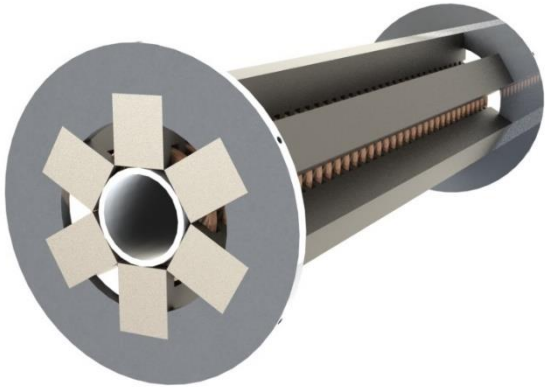
II. Vehicle: Iron-based Capsule with Copper Jacket

III. Vacuum Tube: Evacuated 13 meter Oval Test Track



Double-Sided LIM

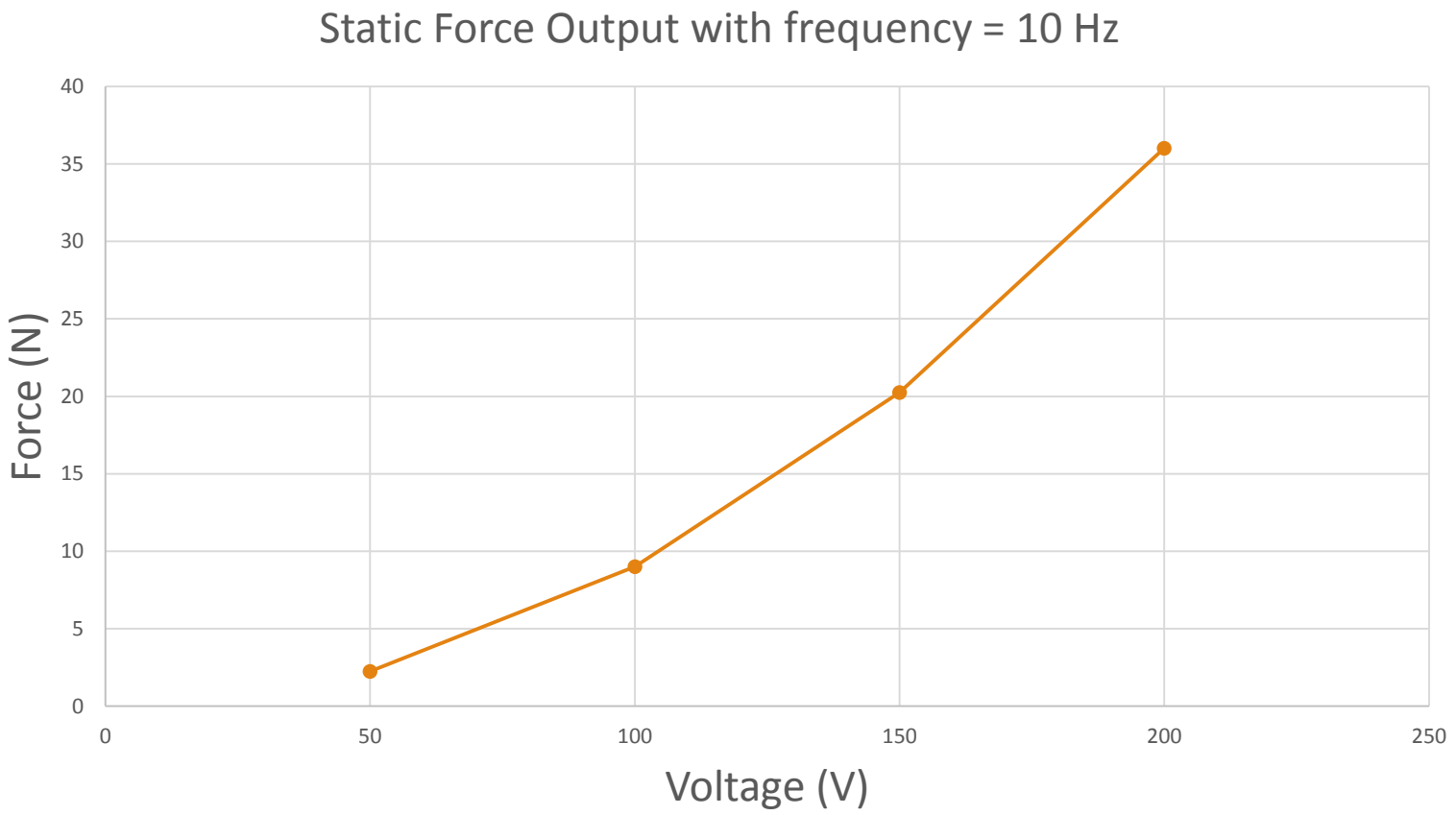
Hyperloop White Paper LIM



Scale Model TLIM

Source: Analysis of a Linear Induction Motor with double sided primary and sheet secondary, Sandeep Bala
http://www.gizmag.com/hyperloop-musk-analysis/28672/

Selected Design Parameters



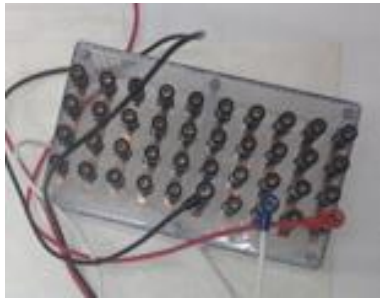
Motor Parameters	
Number of Phases	3
Number of Poles	4
Turns per Slot	217
Slot Height	.75 inches
Stator Back Height	1.75 inches
Stator Width	2 inches
Stator Length	36 inches
Slot Pitch	1 inch
Average Air Gap	0.429 inches
Wire Size	18 gauge
Stator Core Material	M-22 Electrical Steel

Motor Schematic

230VAC
3Ø Power

Yaskawa Motor Drive

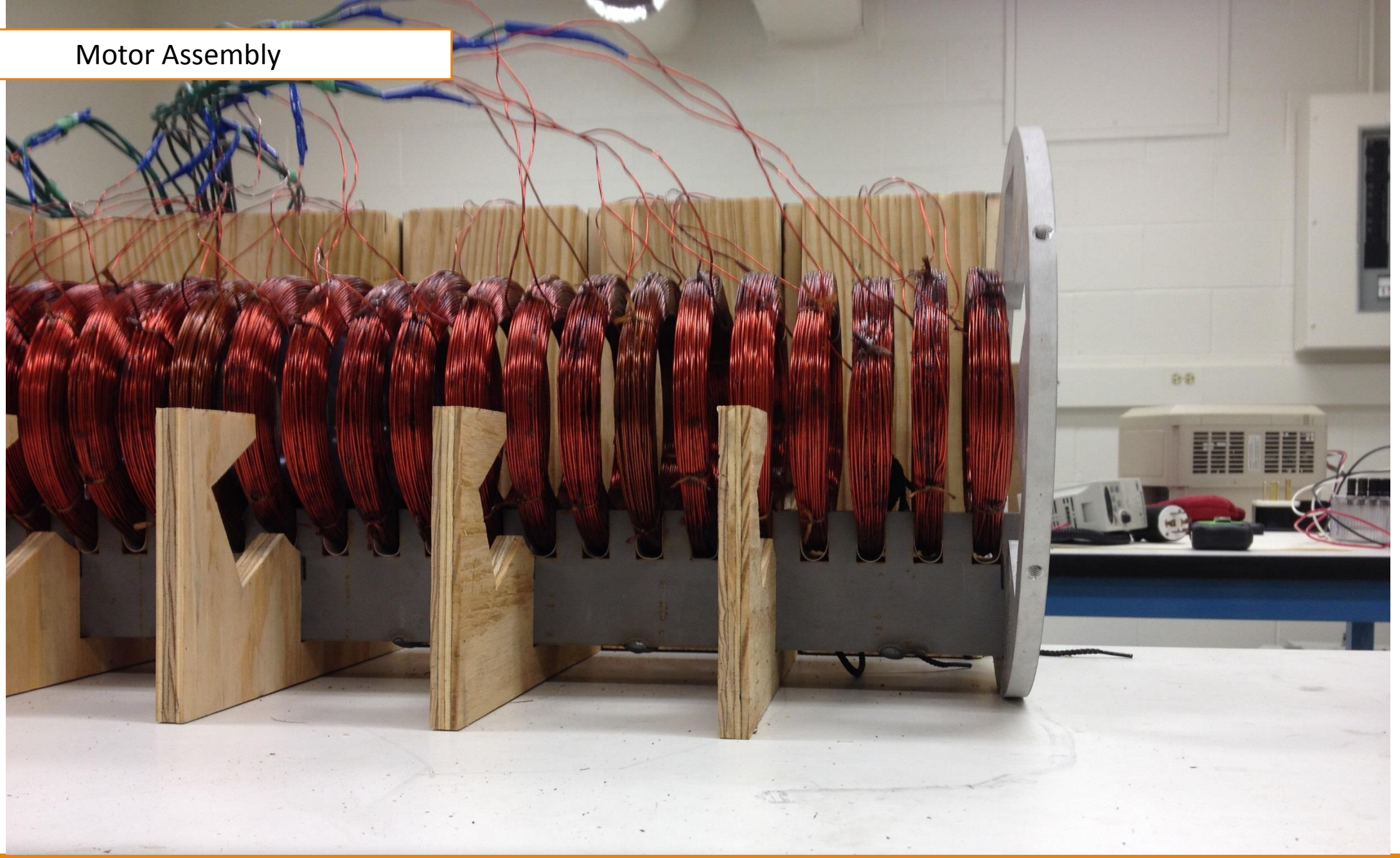
Wiring Circuitry



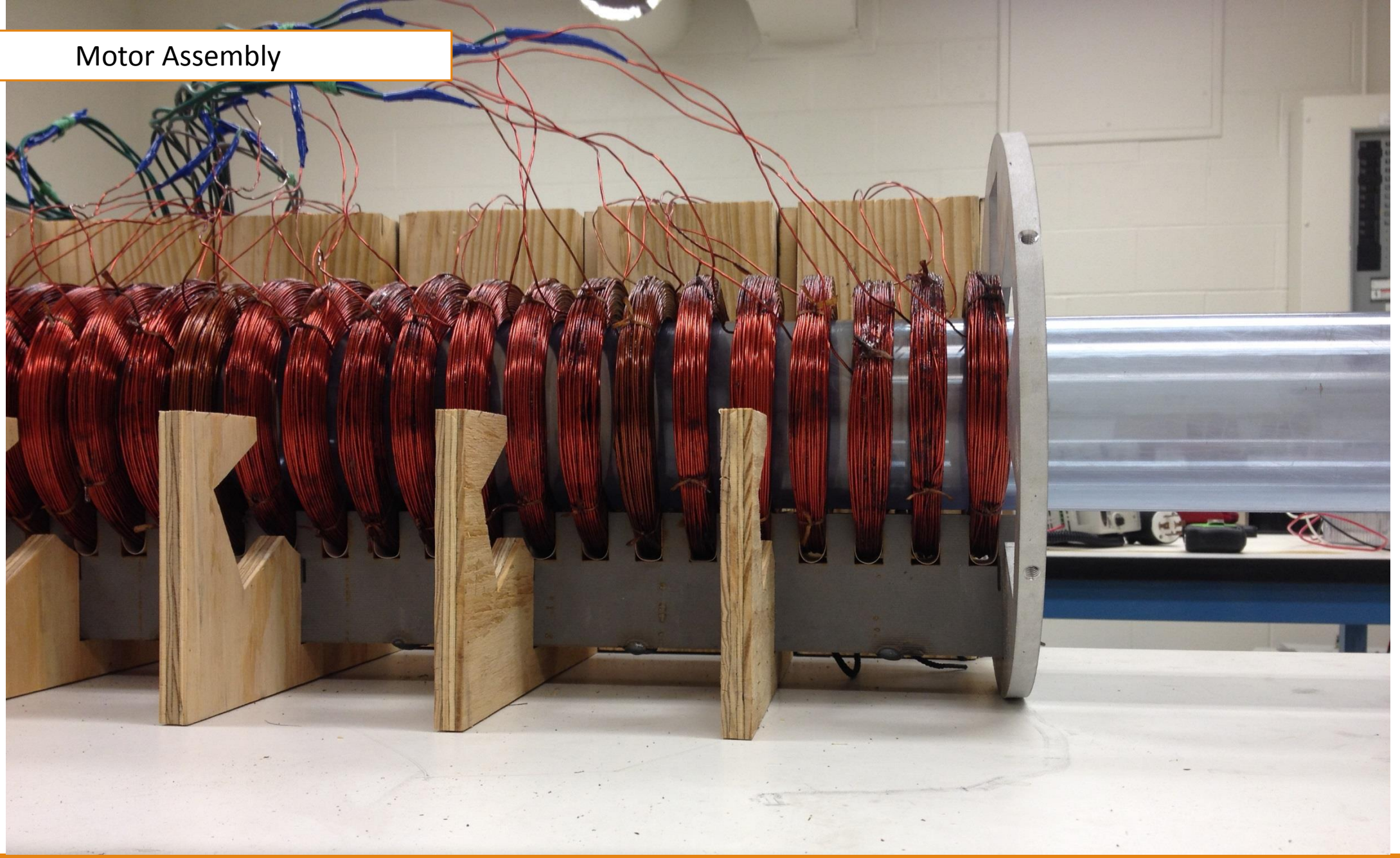
Tubular Linear Induction Motor

Motor Coil Fixture

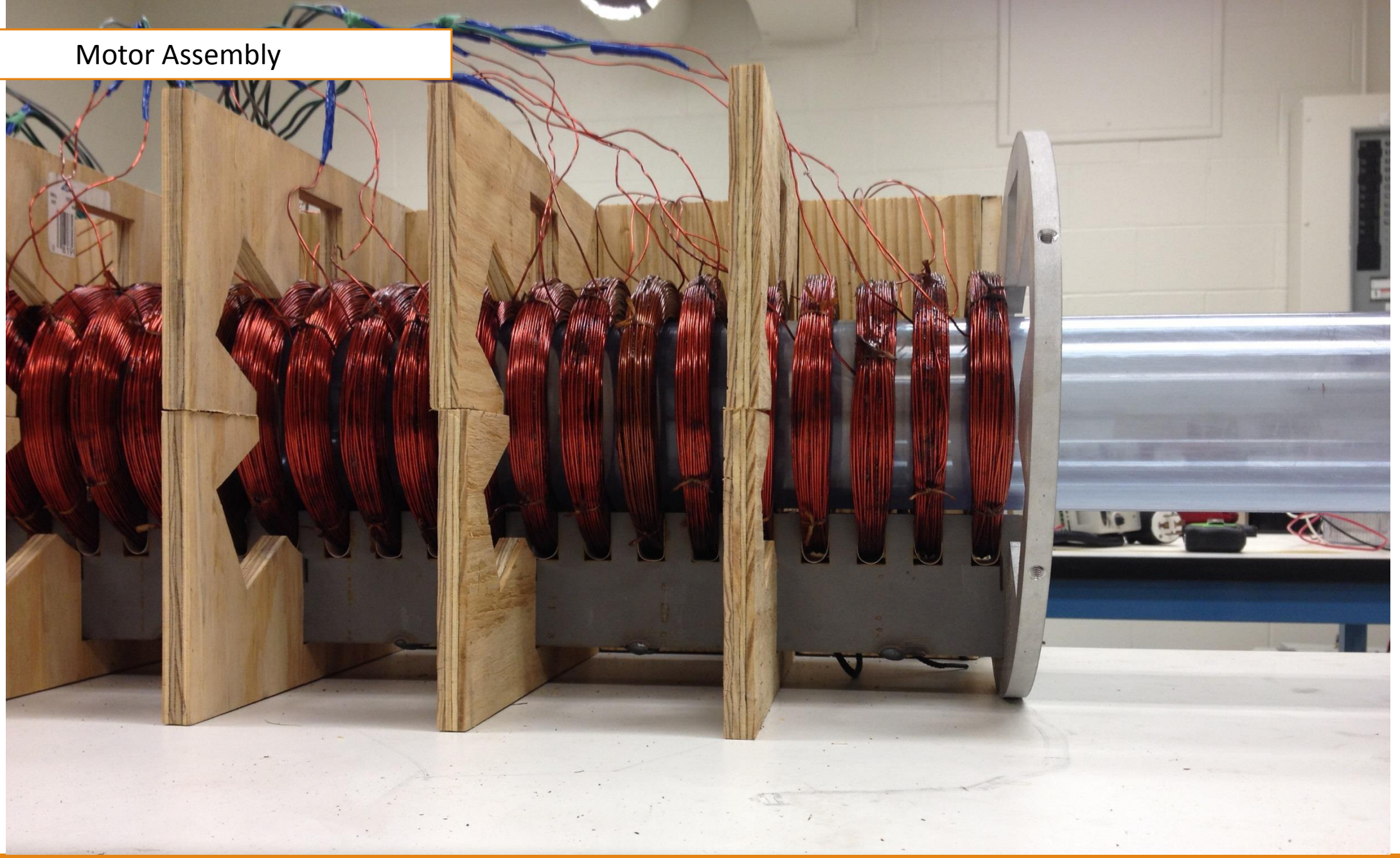
Motor Assembly



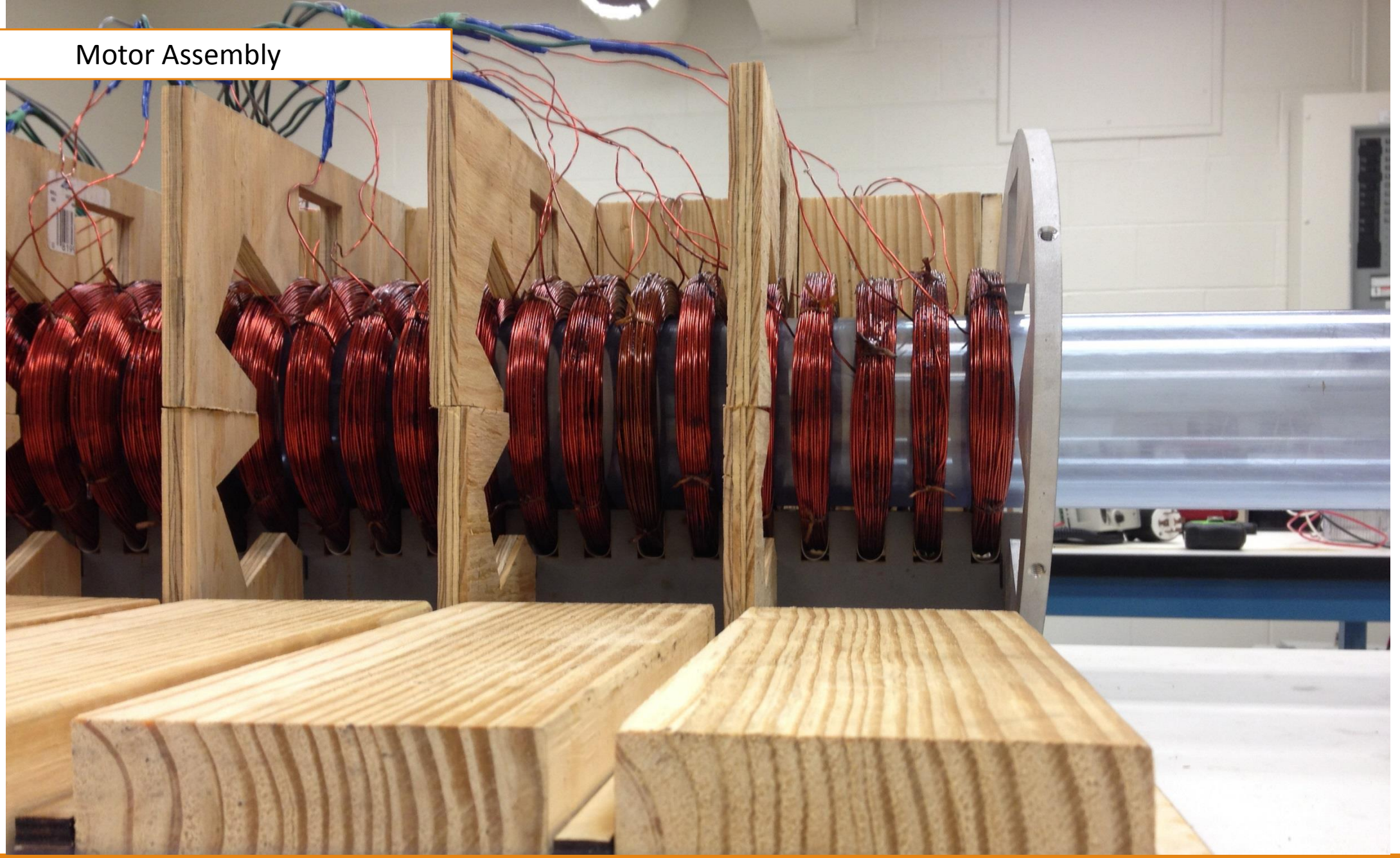
Motor Assembly



Motor Assembly



Motor Assembly

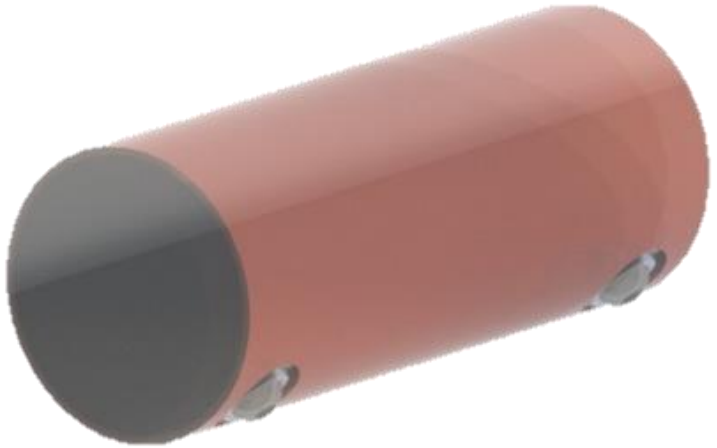


Capsule Results

I. Propulsion System: Tubular Linear Induction Motor (TLIM)

II. Vehicle: Iron-based Capsule with Copper Jacket

III. Vacuum Tube: Evacuated 13 meter Oval Test Track



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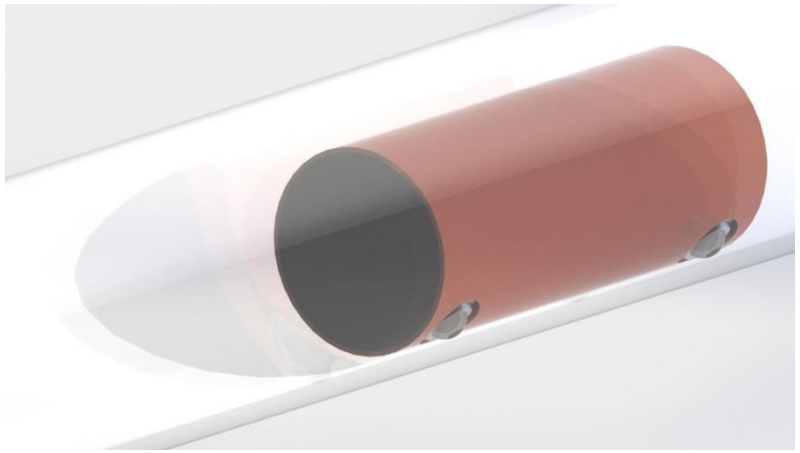
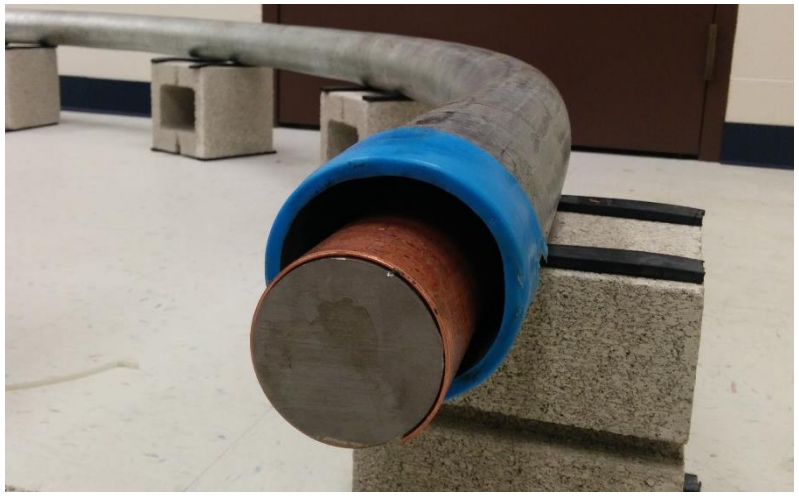
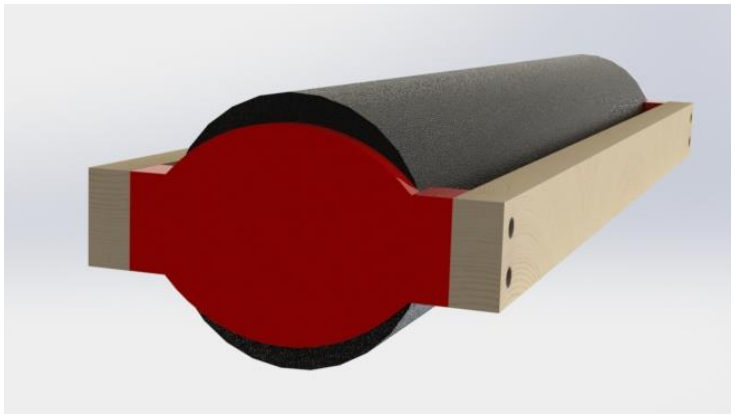




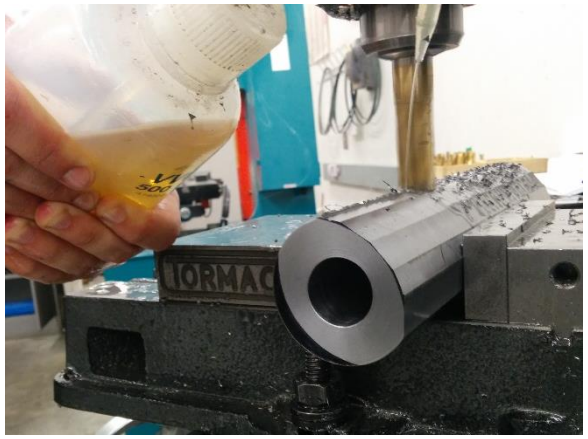
Accelerated capsule manufacture timeline

- Delay in shipping = time to make only 1 capsule.
- Very high machining costs for surface profiling and copper forming = DIY

Iron Profile Manufacture



Cut profile jig



Mill

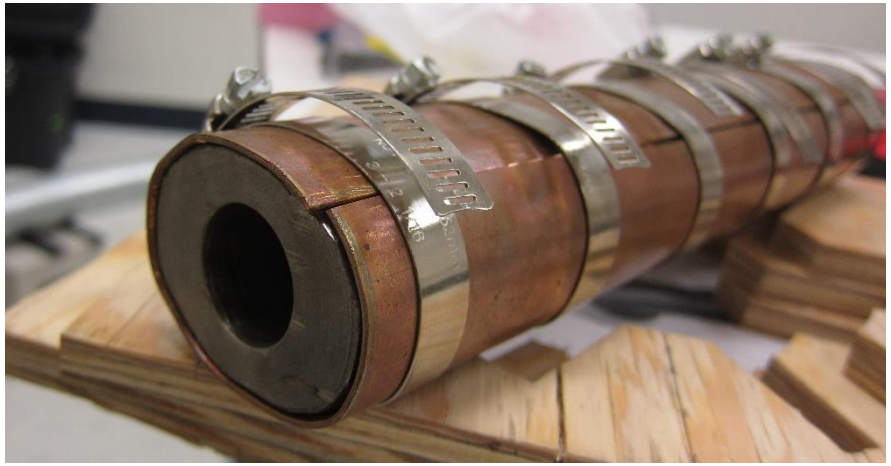
Ready to sand

Copper Forming

Previously cold-rolled copper is cold-worked into iron profile shape.

Copper is clamped and entire capsule is heated to 500°F.

- Recrystallization temperature of copper is 200°C ≈ 392°F [1]
- Stored elastic strain in copper is released, and profile is maintained.



[1] : Brick et al.

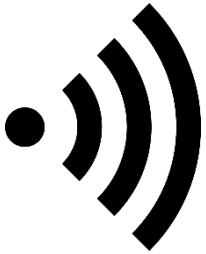
Capsule Control System

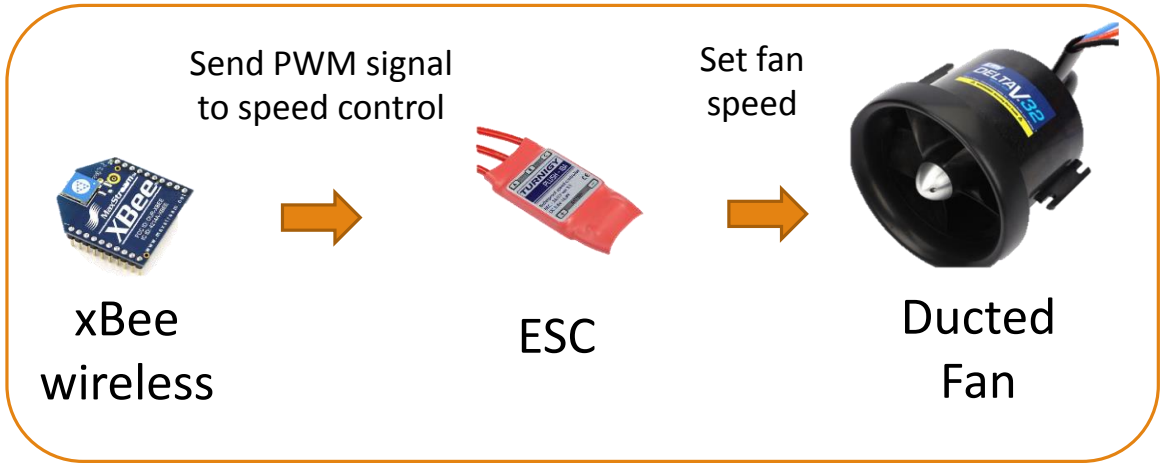
Open-loop Wireless control system diagram

Set PWM speed on computer

xBee wireless

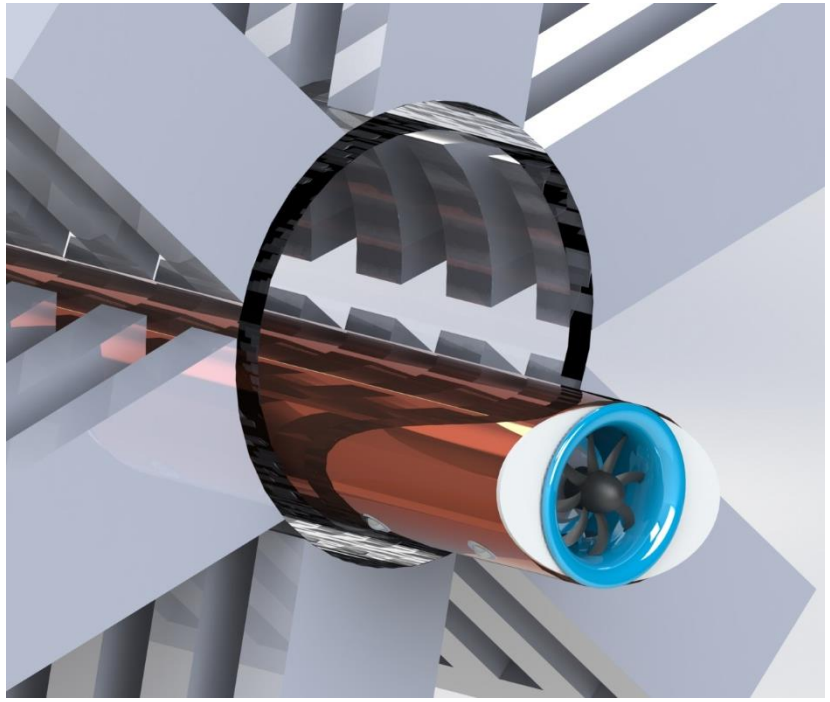
xBee Wireless Serial Communication





Capsule Continued Work

I. Remaining tasks:
   1. Complete capsule braze and bearing install
   2. Integrate control electronics and fan with capsule
   3. Make aerodynamic fairing for fan



Test Track Results

I. Propulsion System: Tubular Linear Induction Motor (TLIM)

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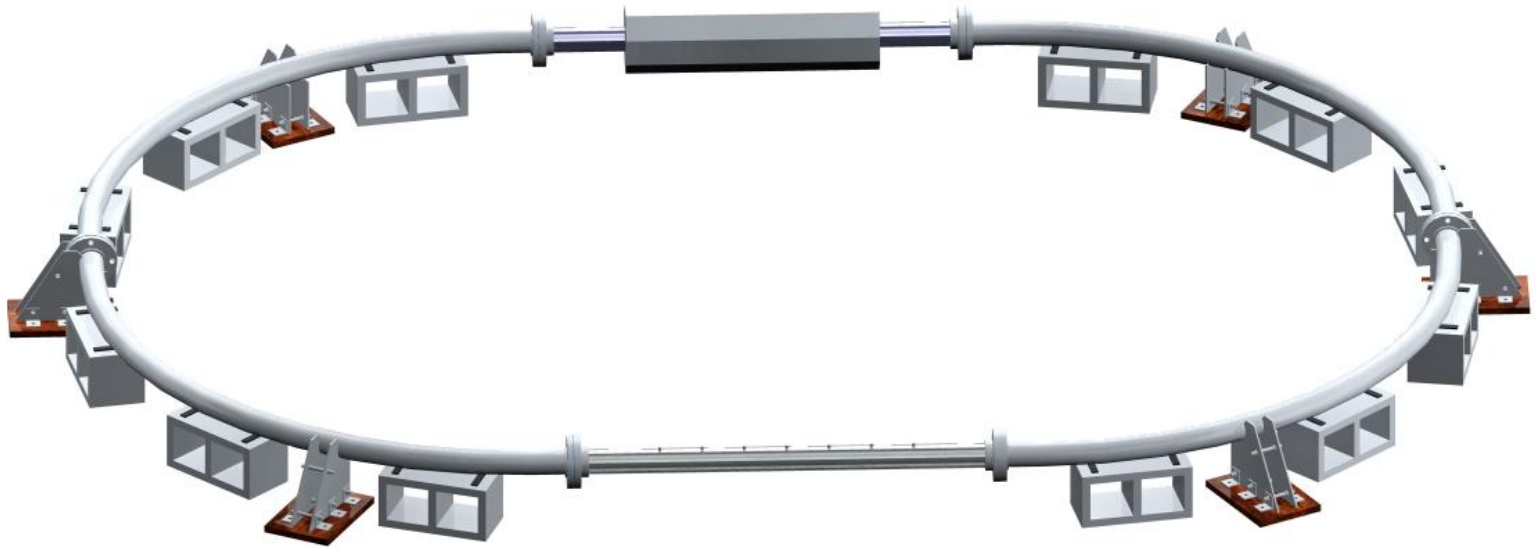
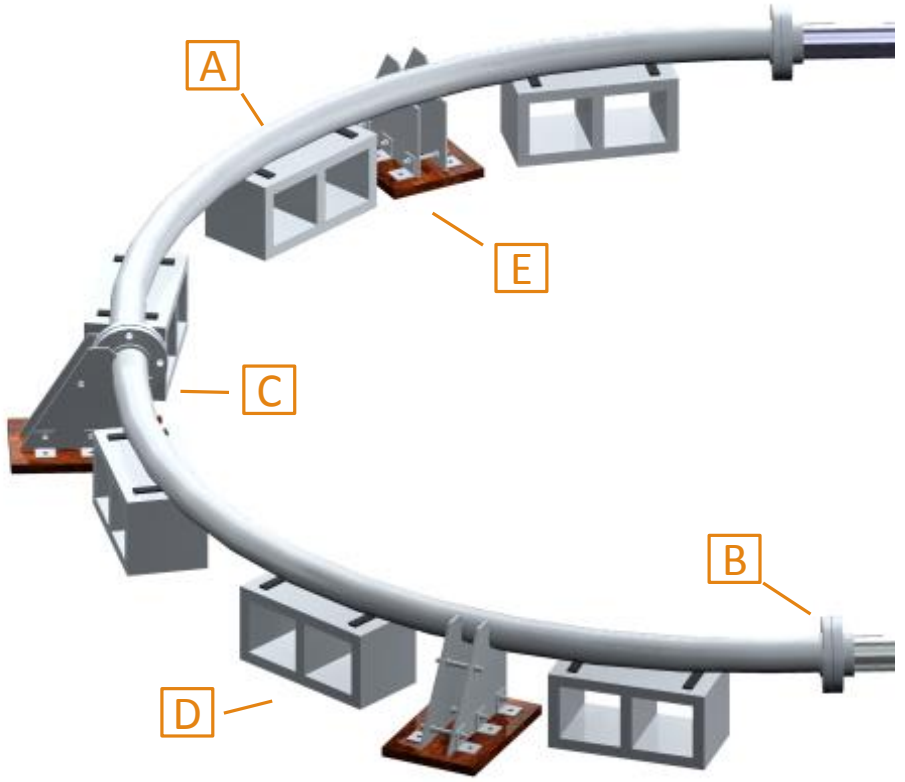
III. Vacuum Tube: Evacuated 13 meter Oval Test Track



Tube Component Status

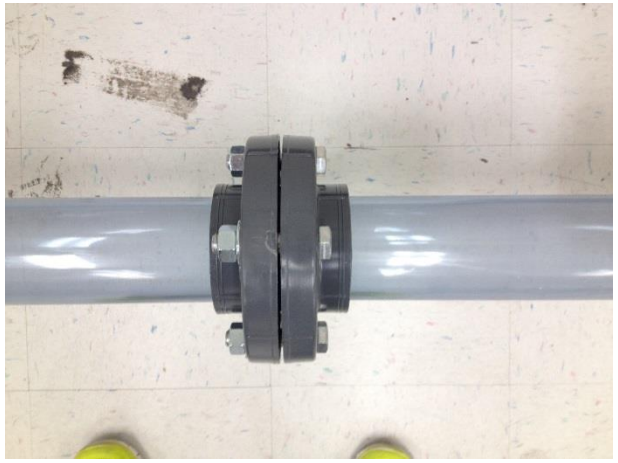
Components

A. Off-the-shelf 60” Radius, 3” Rigid Conduit Tubing
B. Clear PVC straightaways for motor and observation
C. Off-the-shelf flanges steel and PVC flanges
D. Economical vertical support elements
E. Reinforced radial supports



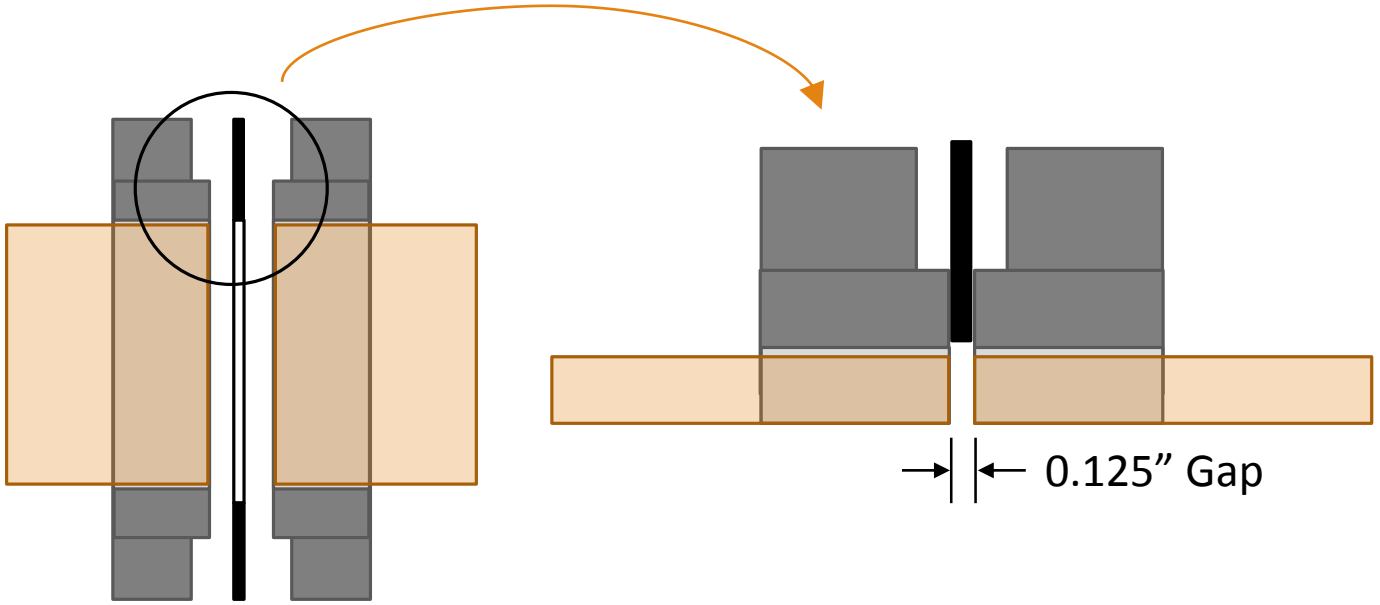
Tube Status

I. Tube
- 90 Degree Steel Elbows: cut, cleaned, and fitted with welded flanges
- PVC Straights: cut and fitted into PVC flanges, ready for gluing



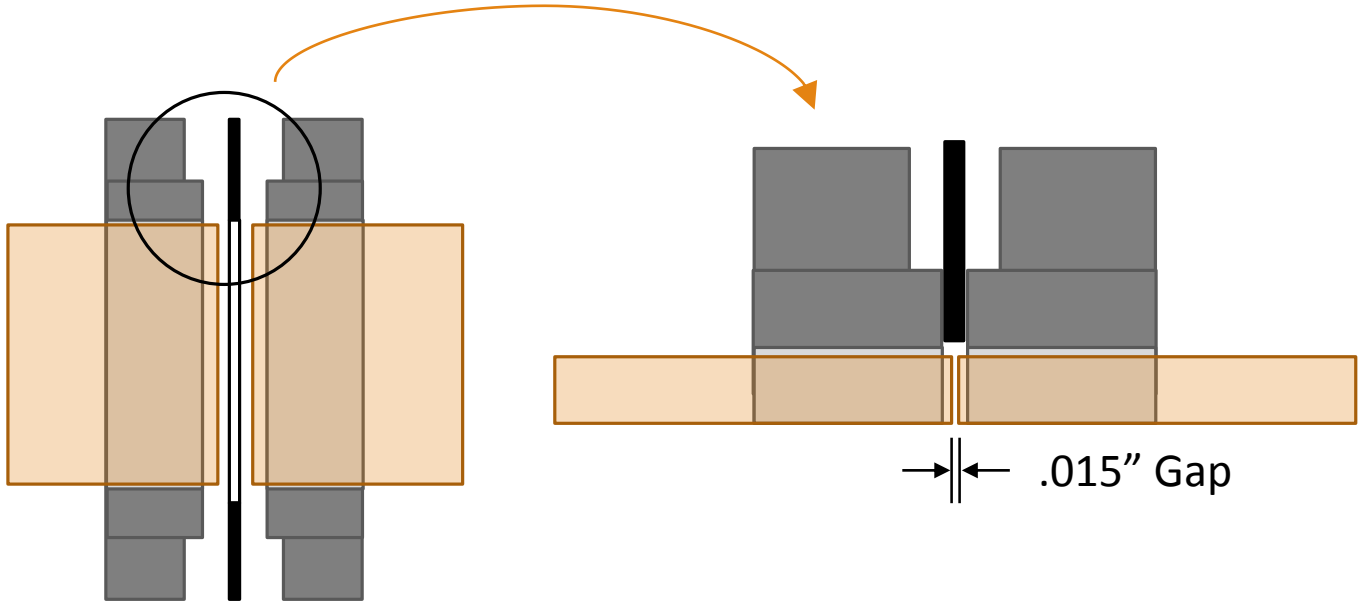
Tube-to-Tube Interface Design

I. Design Challenge: Conflicting Requirements
   - Minimize gaps between tubes
   - Maintain near vacuum



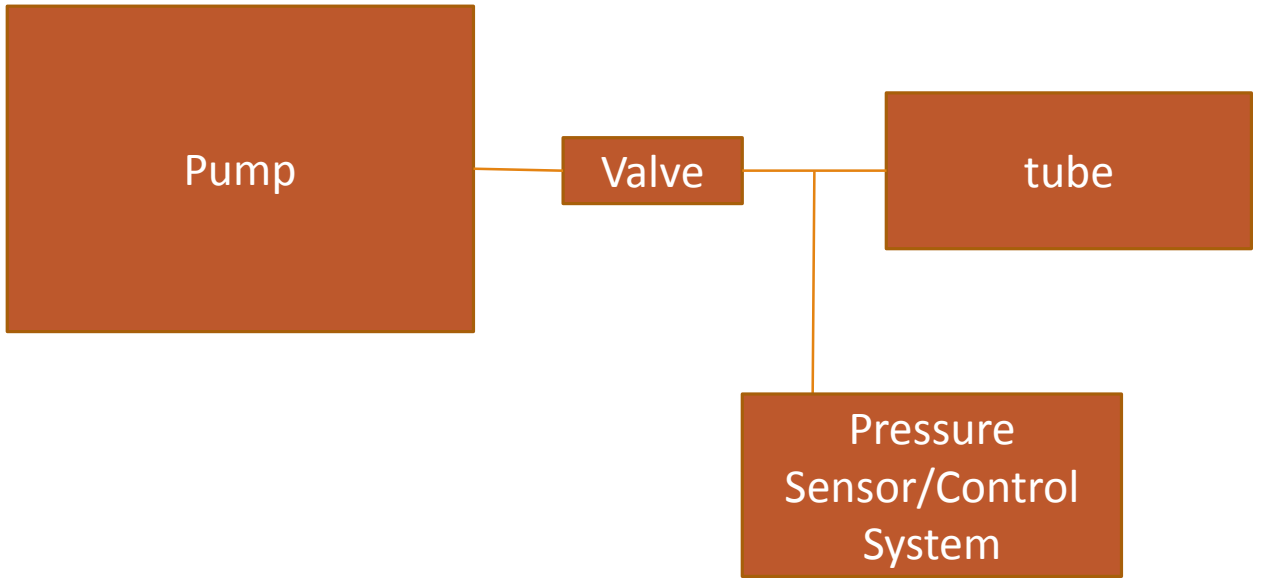
Tube-to-Tube Interface Design

I. Solution: Tube to Seal Face Offset
   - Assume 10% compression of gasket
   - Maximum material condition allows for future tuning



Vacuum System Status

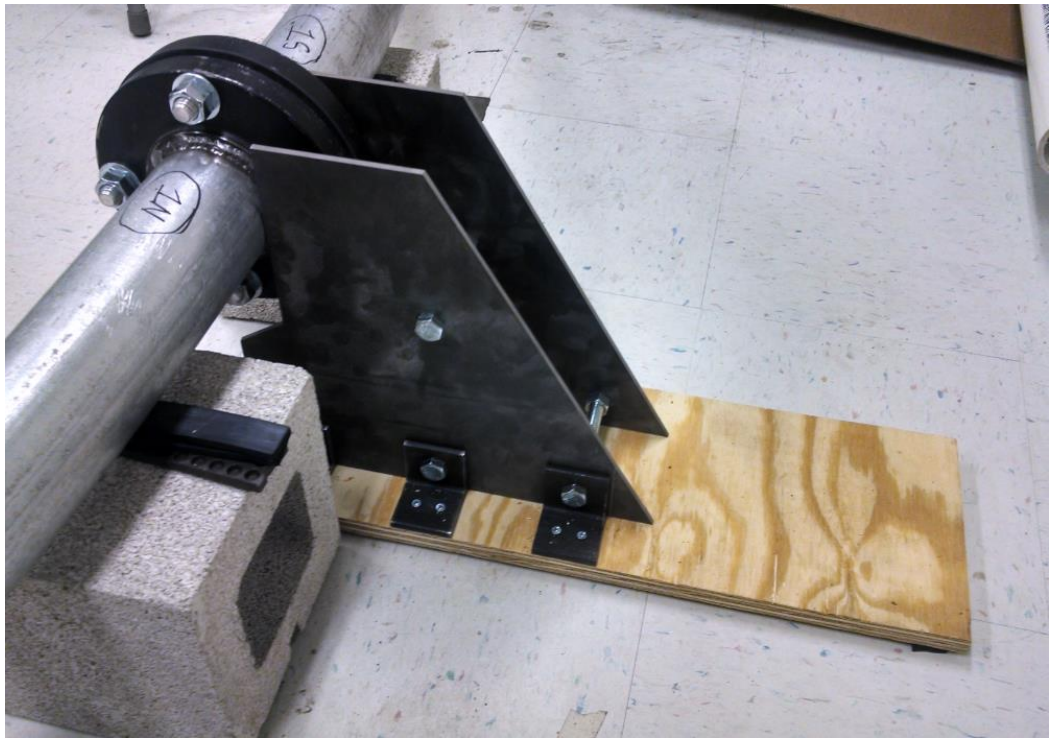
I. Vacuum System:
- Pump acquired, tubing and connection hardware in transit
- Waiting for 3-phase, 230V wiring of pump

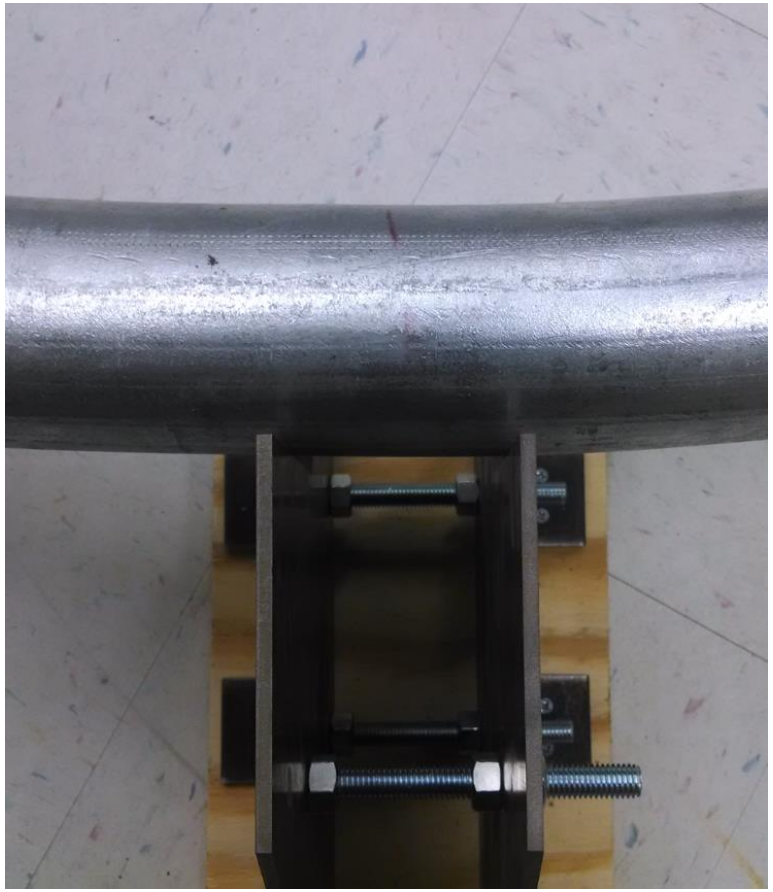


Support Structure

- Provides horizontal support needed to counteract the forces created in the turns by the capsule
- At 30m/s, each support needs to account for 118lb of force (3 supports per turn)
- 3/16” Hot rolled steel plates

Support Structure





Support Structure

Why was this design chosen?

- Does not over-constrain in the vertical direction
- Ease of manufacturing for each sub-component
  - Machining of the steel plates was done with the waterjet
  - Angled brackets were made out of an angled steel bar in the machine shop
- Accounts for different tube heights
- Simple design overall which makes it easy to assemble

Track Continued Work

I. Remaining Tasks For Current Team
   A. Final tube fabrication steps, estimated completion by 5/12
   B. System test with vacuum pump, estimated completion by 5/15

Final Budget

System	Expense Category		Amount
Motor	M-22 Electric Steel	$	1,219.39
	Coil Winding		808.12
	Wiring Equipment and Hardware		804.04
	Motor Subtotal		2831.55
Capsule	Iron core		242
	Copper jacket		54.72
	4x ball transfer bearing		94.72
	Fan electronics		62.97
	Capsule Subtotal		454.41
Track	Steel and PVC Tubing		645.87
	Flanges, Gaskets, and Hardware		814.84
	Vacuum Hardware and Tubing		87.17
	Supports		477.16
	Track Subtotal		2025.04
Grand Total		$	5,311.00

Key Accomplishments Delivered

Motor:

- Custom tubular linear induction motor designed and partially completed

Capsule:

- Capsule designed, partially completed
- Control system and electronics designed and being integrated

Tube:

- Tube system with airtight seals designed and constructed
- Cost-efficient tube structure and supports designed and constructed

Recommendations for Future Work

Tubular Linear Induction Motor:

- Stator dimensions were prohibitively expensive in both time and money
- Finish stator manufacture
- Technical support on the motor drive is needed

Capsule:

- Optimize vehicle shape / cross-section profile
- Optimize vehicle ride height
- Integrate microcompressor for air ski
- Suspension

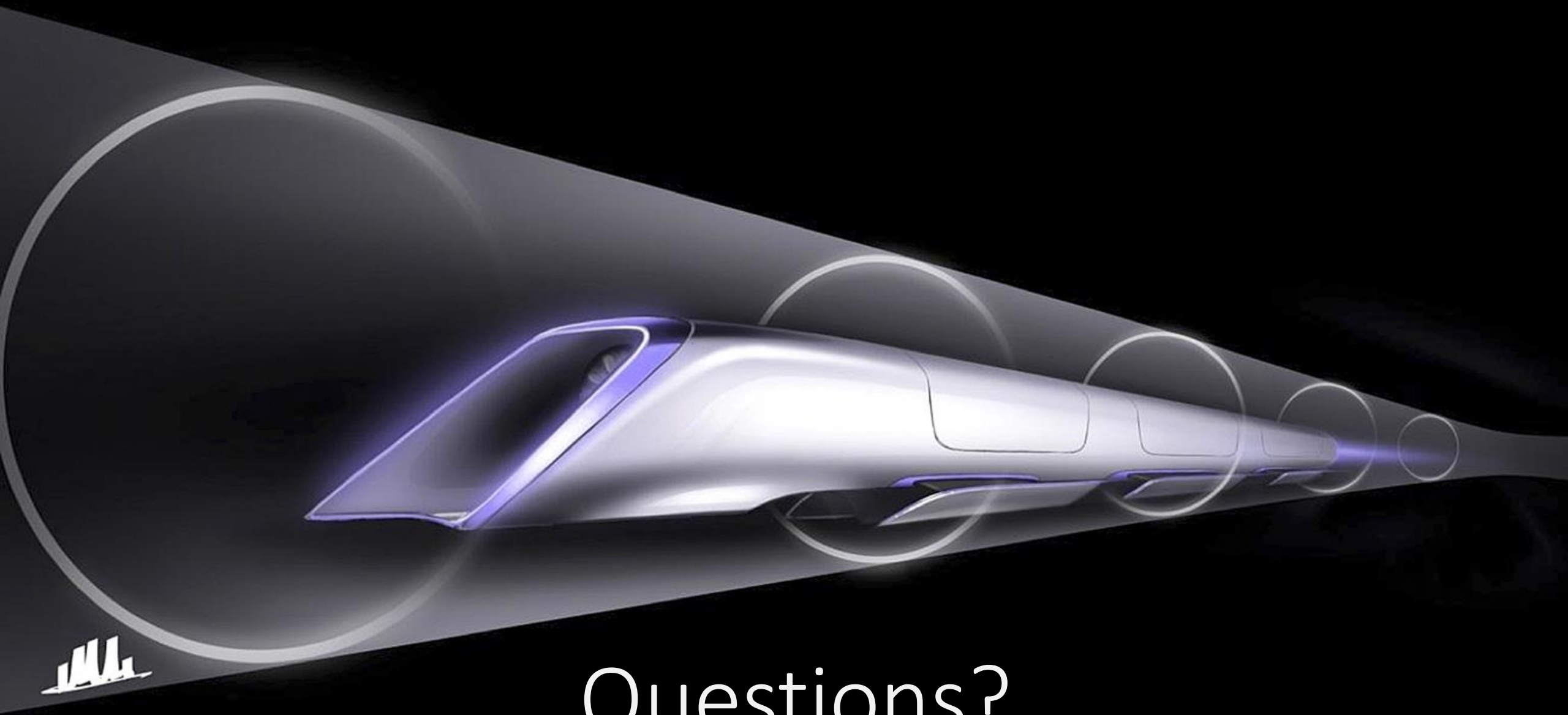
Tube:

- Integration with motor and capsule systems
- Testing of track levelness and smoothness
- Refinement of tube sealing
- Implementation of vacuum control system
- Further implementation of capsule performance sensors

Acknowledgements

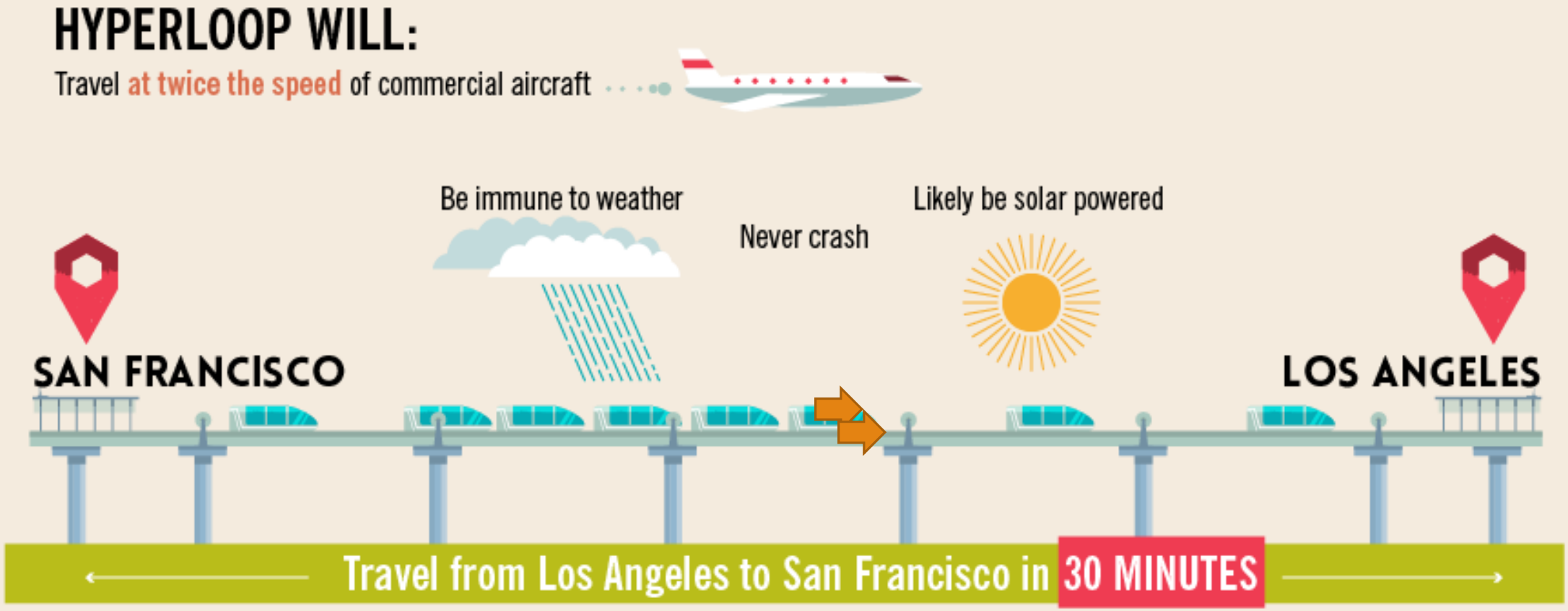
Special thanks to the following:

Advisor	Professor Pantano-Rubino
Advising TA	Conrad Smith
Initial Project Inspiration	Professor Ferreria
Fabrication and Design Advice	MechSE Machine Shop Staff
Motor Design Advice	Matt Magill, Chris Barth
Motor Fabrication Advice	ECE Machine Shop
Power Electronics for Motor	Kevin Colravy



Questions?

Why is it better?


HYPERLOOP WILL:
Travel at twice the speed of commercial aircraft
Be immune to weather
Never crash
Likely be solar powered
SAN FRANCISCO
LOS ANGELES
Travel from Los Angeles to San Francisco in 30 MINUTES

Motor Skeletal Support

- 7 pieces of 1/2” thick plywood
- 2 pieces of 3/8” thick aluminum
- Design criteria included minimization of cost and ease of machining
- $\delta_{max} = \frac{-PL^3}{48EI}$ $\quad$ $\mathrm{I} = \frac{bh^3}{12}$
- $\mathrm{h} = 1.75\ \mathrm{inch}$
- $\delta_{max} < .0394\ inch\ (1\ mm)$

Motor Drive

- Brand: Yaskawa
- Model: 515/G5
- SPEC: 27P51F
- Nominal Horspower: 10 HP

	Number of phase	Voltage (V)	Current (A)	Frequency (Hz)
Input	3	200-230	40 A	60
Output	3	0-230	33 A	0 - 400

Linear Induction Motor

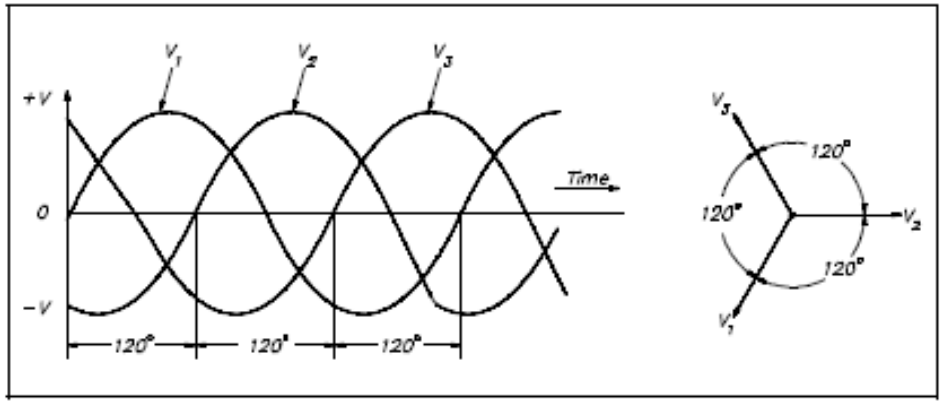
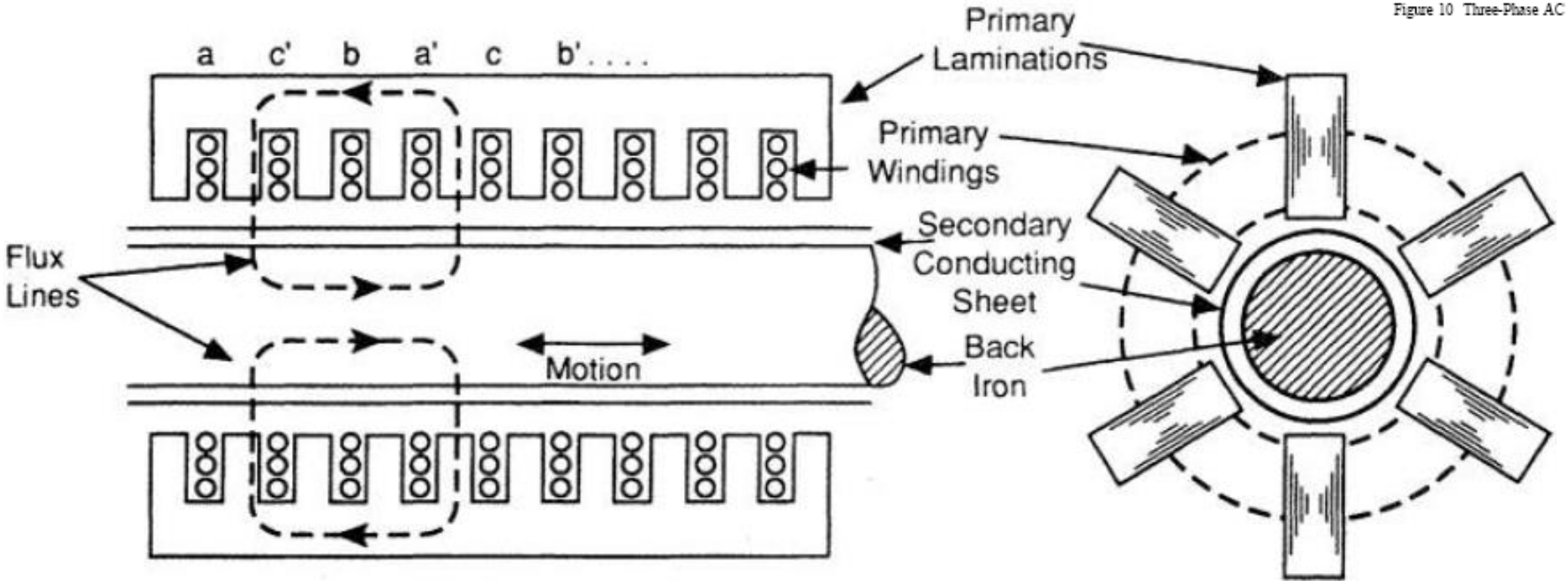
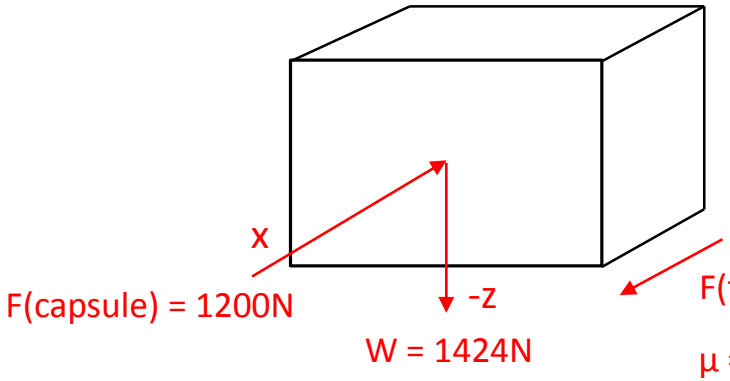


Figure 10 Three-Phase AC



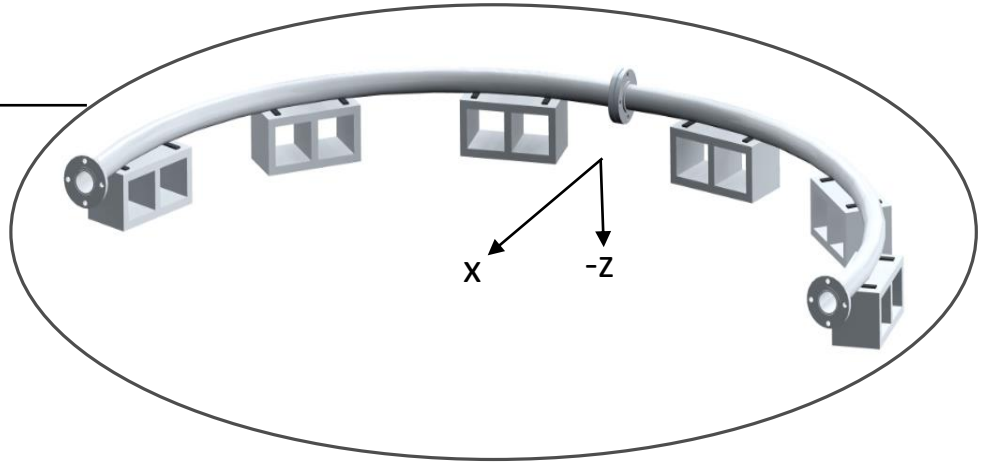
Source: Handbook of Electric Motors, Hamid A. Toliyat and Gerald B. Kliman ,
http://knowledgepublications.com/doe/images/DOE_Eectrical_Science_Three-Phase_AC.gif

Design Problem – Tube Support

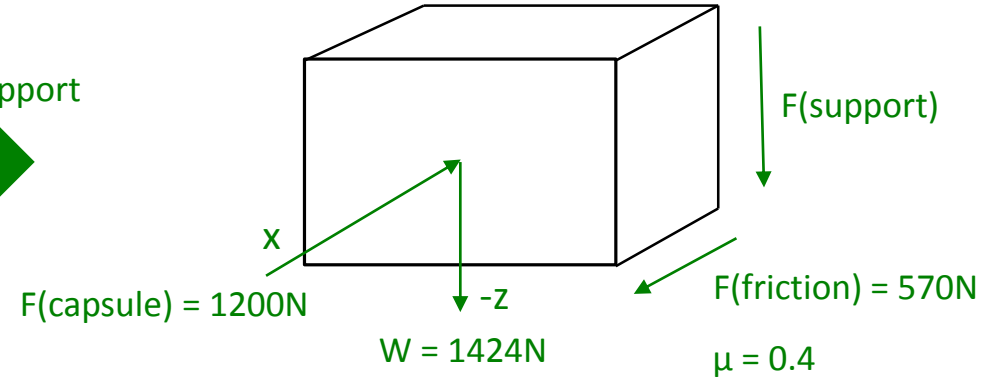


Simplification

F(x) = -1200 + 570 = -630N ≠ 0



With lateral support



F(x) = -1200 + 570 + 0.4F(support) = 0

F(support) = 1575N = 354 lb per turn